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Before the
Federal Communications Commission
Washington DC 20554

In the Matter of	)	
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Inquiry Regarding Software Defined Radios	)	ET Docket No. 00-47
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	)	

COMMENTS OF
SBC WIRELESS INC.

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SUMMARY

SBC Wireless is excited about the prospects for SDR. SDR can improve the cost and operation of wireless networks through network equipment that is smaller in size, more flexible, less costly and easily upgradable.

The NOI is timely because much has been written about SDR and its characteristics and benefits. Unfortunately, many times the term SDR is used in a generic sense without explanation of the specific context thus leading to confusion. A better understanding of the term SDR is achieved by separating the concepts of bandwidth and implementation approach. A radio system may be based upon SDR while operating over a very limited RF bandwidth. Conversely, a conventional radio, using a more dedicated hardware, may operate over wide frequency bands. Thus a radio system may be software defined without being wideband and vice versa.

In the near term, SDR is primarily an implementation technique, a method for radio system designs, and has no intrinsic ability to make spectrum use more efficient or flexible. While implementing radio systems using SDR technology shows the promise to deliver a number of significant advantages, the NOI goes further. It discusses the use of such technology in terms of allowing access to a wide bandwidth of spectrum and enabling a handset that can operate across wide frequency bands, using multiple air interfaces. It is the belief of SBC Wireless that such use is not technically or commercially feasible at this time. Care must be taken in making sweeping assumptions about the ability of such systems. Given such, the Commission should not consider

changes to spectrum allocation approaches.

The one area where the Commission should consider taking action is that of equipment certification. If a common hardware platform is used to implement multiple standards then it is not just the hardware or just the software that needs to be certified, but the combination. Any software change, or addition, that would have an impact on the RF performance of the equipment should require a new certification. Some flexibility in software changes to allow application software and other modifications that do not impact RF should be allowed without recertification.

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Now Comes SBC Wireless Inc. and files these Comments in response to the Commission's Notice of Inquiry regarding Software Defined Radios (SDR).[1] SBC Wireless is excited by the prospects of SDR and welcomes this opportunity to provide Comments. SBC Technology Resources, Inc., the SBC Communications Inc. technology research affiliate, has been directly involved in the study, analysis and testing of wideband and software-defined radio for several years and believes that SDR holds the potential to bring great benefits to equipment vendors, system operators and the customer. SDR can improve the cost and operation of wireless networks through network equipment that is smaller in size, more flexible, less costly and easily upgradable. The NOI is timely because much has been written about potential benefits and efficiencies that can be achieved through SDR. Unfortunately, SDR is often referred to in a generic fashion thus giving rise to a broad all-inclusive definition. SBC Wireless is concerned

[1] In the Matter of Inquiry Regarding Software Defined Radios, *Notice of Inquiry*, Released March 21, 2000. ("NOI").

with the implications of some of the characteristics and capabilities that have been ascribed to SDR and welcomes this opportunity to share its views.

I. UNDERSTANDING SDR REQUIRES AN EXAMINATION OF THE CONTEXT IN WHICH IT IS BEING USED

As noted above the meaning of SDR is not always well defined. SDR is sometimes used, including in the NOI, to denote a system that has access to a wide bandwidth of spectrum and in which the radio functionality is implemented in software upon a digital platform. A more precise understanding of use of the term SDR can be achieved by separating the two concepts of bandwidth and implementation approach. A radio system may be based upon SDR technology while operating over a very limited RF bandwidth. Conversely, a conventional radio, using a more dedicated hardware, may operate over wide frequency bands. Thus a radio system may be software defined without being wideband and vice versa. This is an important distinction that must be kept in mind when discussing the abilities of SDR systems and the approach to spectrum allocation and efficiency. Many of the capabilities described in the NOI may require very wideband RF front ends, which are not yet technically feasible. However, a radio system may be designed and implemented using an SDR approach even within a limited RF bandwidth, and achieve a number of benefits. Such seemingly is the most imminent use of SDR.

Using SDR implementation techniques, significant benefits accrue to both the infrastructure and the terminal equipment. An equipment vendor using SDR techniques to develop a wireless base station can develop a common platform on which to host software for a particular wireless standard. For example, the base station common platform could support the vendor's GSM and ANSI-136 product lines. This would lead to greater efficiencies and higher volumes for hardware, resulting in a lower cost product. In addition the product would be more flexible because, within the capabilities of the underlying hardware, a new standard could be implemented through the development of different software. Likewise upgrades to existing standards could be implemented with software changes as opposed to changing out hardware. This would result in cost efficiencies for the vendor and the system operator alike.

While there has been some discussion, including in the NOI, in terms of the potential for a multimode SDR-based base station that could simultaneously serve multiple mobiles using a large number of different air interfaces, SBC Wireless does not see the technology being used in this fashion. While such a multimode base station may be possible, the operation of such a station would require the operator to fragment its licensed spectrum to address the different types of air interfaces. This is because each standard has its own control channel structure, RF bandwidth, reuse requirements and other criteria and such cannot be done in a purely dynamic function while providing a deterministic quality of service. In addition to providing multiple modes, SBC Wireless sees the true value of the SDR-based base station in its flexibility and upgradability. In addition, the SDR-based base station can enable new techniques that can have significant impacts on cost of operation and spectral efficiency. For example, a SDR-based base station, through the use of proper RF front end and internal architecture, can integrate adaptive antenna processing, in addition to the standard baseband processing, in a cost effective matter. Also, by digitizing the signal space prior to final channel filtering, better filter characteristics may be achieved. These factors should lead to reduced frequency reuse requirements thus allowing the operator more efficient use of the licensed spectrum. Thus, the most imminent operational benefit from SDR-based base stations will be in terms of flexibility and the resulting efficiencies.

In the handset a SDR platform would provide the ability to take on the best "personality", or standard for the situation. A SDR platform in the handset would allow for easy upgrades, possibly over the air, when changes are made to standards or new applications are developed. This, of course, presupposes that the design of the terminal will accommodate the change. Care must be taken however in making sweeping assumptions about the ability of such systems. The use of wide RF front-ends presents significant handset challenges, most notably in terms of size of the handset and the high levels of processing power required. The public preference for small, lightweight handsets with long battery lives is at odds with wider RF bandwidths and higher processing level requirements. Thus, while a handset that can operate across wide frequency bands, select available spectrum and adapt to the system standard in such band sounds appealing, it is not yet technically or commercially feasible. There is also concern about the commercial feasibility associated with such dynamic roaming on, or sharing of, other carriers' networks.

Thus, in the near term, SDR is primarily an implementation technique, a method for radio system designs, and has no intrinsic ability to make spectrum use more efficient or flexible. SDR does not, by itself, improve spectrum efficiency or change the manner in which wireless networks must be designed and operated. The bottom line is that while SDR shows great promise in improving the performance and cost effectiveness of wireless networks, it is not likely to provide all the capabilities ascribed to SDR in this

NOI. The same physical laws apply, propagation and frequency reuse issues are the same, and there must be a degree of control in the networks if carriers are to provide customers with a quality product. Given such, the Commission should not consider changes to spectrum allocation approaches, at least not until a wide deployment of SDR equipment has been made and further study and experimentation show that there are preferable alternatives.

The one area where the Commission should consider taking action is that of equipment certification. If a common hardware platform is used to implement multiple standards then it is not just the hardware or just the software that needs to be certified, but the combination. Any software change, or addition, that would have an impact on the RF performance of the equipment should require a new certification. However some flexibility in software changes to allow application software and other modifications that do not impact RF should be allowed without recertification.

II. RESPONSES TO DIRECT QUESTIONS POSED BY THE NOI.

The NOI requests comments and opinions on several specific questions and areas regarding SDR. SBC Wireless and SBC Technology Resources, Inc. have collaborated to provide the following responses:

A. State of software-defined radio technology

- *What features in a radio are apt to be controlled by software? For example, could the operating frequency, output power, and modulation format be software controlled?*

Several features in a software defined radio are apt to be controlled by software. For example, many base band functions such as modulation, channel coding, interleaving, and source coding will be controlled by software. Operating frequency, baseband bandwidth, RF bandwidth, output power, and filtering will also be controlled by software. However, there will be limitations in this flexibility due to component performance (particularly in the RF) and limitations in memory and processing resources.

- *What are the specific limitations of current software defined radio technology? What are the cost implications?*

There are significant benefits to be achieved through the use of wideband and SDR technology, but there are a number of challenges to overcome. These challenges generally fall into two categories, technology and business. The challenges in technology relate primarily to required advances in component technology. The severity of the challenge depends on whether the SDR is used in a handset or a base station, and depends on the type of air interface. Some of these challenges are listed below in Table 1.

Table 1: Wideband/Software-Defined Radio Challenges

Challenge	Areas of Interest
Dynamic Range	Differing specs, A/D, D/A, Power Amp, component linearity
Resolution	Accuracy of representation from A/D
Power Consumption	Handset design – required processing power, RF bandwidth
Processing Power	Power consumption, ability to process wideband signals, high performance DSPs
High Speed Bus	Transport of multiple streams of high rate digital data in the base station
MCPA – Multi-Carrier Power Amplifier	IMD performance, linearity, number of carriers, power output, spurious emissions
Cost	High performance components
Software	Modularity, download, reuse, partitioning, resource allocation, configuration control
Memory	Amount required, speed, silicon real estate, partitioning, off-board vs. embedded
Standards	How are standards impacted by the new paradigm, ability to change

Measurement techniques	Some measurement specs in standards not valid for wideband systems
RF	Wideband components, linearity, cost, tunability, wideband antennas

The challenges listed in Table 1 are by no means all-inclusive, but represent the major challenges to the industry. How these challenges are addressed depends a great deal on the philosophy of system design. One of the primary determinants of component requirements is the question of how close to the antenna the signal is digitized. As digital hardware moves toward the antenna (digitize sooner in the process), it brings the advantages of rapidly advancing microelectronics technology. These include, among others, lower power, reduced production costs, higher levels of component integration and better stability. However, this also increases the demands placed on component performance.

One important technical challenge that prevents SDRs from operating over a wide range of frequencies and bandwidths is the required advances in RF component technology. In order for a SDR to perform such operations, wideband RF filters and amplifiers are required that have a large tunable range, good linearity, and reasonable cost. There are some serious challenges in this area that need to be overcome before one can design a SDR that is truly flexible in terms of the frequencies and bandwidths over which it can operate. This is one of the more difficult challenges facing the types of operational scenarios envisioned by the FCC. Wide bandwidth and tunable RF devices, along with high-speed analog-to-digital (A/D) converters achieving very high spurious free dynamic range are required. Historically, advances in A/D converters have not followed the same performance improvement curve that we have seen for other electronics such as microprocessors and digital signal processors.

The second type of challenges that need to be overcome to reap the benefits of software defined radio technology are related to business issues. There is currently a large embedded base of infrastructure and handsets in commercial wireless networks. As new SDR-based base stations and software defined handsets are developed, they will slowly replace the existing embedded base of equipment. The rate at which the embedded infrastructure is replaced will depend upon cost efficiency and other business factors. These challenges are not directly addressed by the advancement of SDR technology, but are driven by business case issues. Clearly, the sooner the embedded infrastructure is replaced, the sooner the full benefits of SDR technology can be reaped, but the cost will be high. Hence, it may many years before the penetration of SDR equipment reaches a dominant level in commercial wireless networks.

- *What capabilities could software defined radios have that are not found in current radio technology?*

The wideband and software defined radio provides a number of advantages to the manufacturer and service provider alike. It may emerge as a key enabling technology for a number of advanced techniques, and start the move toward the "future-proof" wireless infrastructure and handset.

A base station using a narrowband architecture requires a separate transceiver for each RF carrier it receives and transmits. In a wideband architecture there is a common RF front-end transceiver for all carriers. Thus, to add channels, the operator need only add more baseband processing power via the use of more digital signal processors ("DSP"). This results in a highly compact, inexpensive, and flexible architecture.

All signal information in the operating band may be made available to all DSPs, and filtering may be done in the DSP. This leads to the ability to process different center frequencies, bandwidths and even protocols in each DSP simultaneously. All that's required is that the proper software be resident. It also means that a given DSP can change the function it is performing at any time by downloading new software from the memory store. Thus, for example, the DSP can process an AMPS call in one moment, an ANSI-136 call the next, and an EDGE call thereafter. Different DSPs may also be processing different protocols simultaneously (e.g. ANSI-136 and EDGE). For example, an operator would no longer be required to put either analog or digital radios in the base station, with a resulting static assignment of resources, rather this could be fully dynamic on a call by call basis if desired. Of course, protocols requiring different channel bandwidths and/or reuse patterns will require some level of spectrum segregation. In addition, as protocols change, or new modulation techniques are developed, they can often be implemented in the base station with no hardware changes, requiring only a new software upgrade if memory and processing power are available.

This flexibility, and the digitization of the band, also makes it more cost effective to implement fully adaptive smart antennas. In today's commercial smart antenna approaches, a separate piece of equipment is placed between the antennas and the base station. This is known as an applique. This applique must take the antenna inputs, perform the array processing, recreate the RF signals and then present the base station with the expected antenna connections and signals. This effectively requires equipment that is nearly as complex and costly as the base station itself. In array processing, the signals from multiple antennas are processed for each of the desired channels in order to improve performance through interference rejection or beam forming. For each channel the base station is to process, there must be a radio on each antenna element. So if an operator wants to perform fully adaptive processing using a 6 element antenna array and process 60 channels (equivalent to current base stations with 3 sectors of 20 RF channels each), this would require 6x60 = 360 separate narrowband radios. In contrast, the wideband system uses one RF front end per antenna element and enough DSPs to process the 60 channels. This leads to a tremendous reduction in hardware, with a resulting reduction in cost. This processing can be integrated directly into the base station, resulting in greater flexibility and capabilities, at much lower cost.

Other techniques being studied to improve the performance of wireless systems include the use of frequency self-planning and dynamic channel assignment. In frequency self-planning, the base station monitors its environment and determines the best channels for use in a given location without operator intervention. Having all channel data available to all DSPs in the base station makes this process simpler and cheaper to implement than in narrowband systems. The next step in capability would be to allow the base station to select any channel in the band that will give it the best performance at any point in time, this is known as Dynamic Channel Assignment (DCA). Again, having all channels available to each DSP, along with the performance of digital filtering, makes this more viable than in narrowband architectures. The wideband architecture supports these capabilities intrinsically.

The ability to examine the entire band of operation in the digital domain enables the characterization of the band within the radio. This may open new avenues for adaptive techniques to improve wireless system performance and increase functionality. Valueadded functions and services may be used to improve service and differentiate products and service providers. Note that much of the discussion has assumed a RF front end at least as wide as the provider's operating bandwidth.

In the near-to-mid-term, it may become feasible to implement handsets using SDR. The desirability and viability of a wideband RF front end for a handset is less certain. These components have higher power requirements than a narrowband front end, and it may not be feasible to implement a wideband front end in a handset for some time. Also, few handset concepts call for simultaneous multi-channel operation at this point. However, with a SDR implementation, it may become feasible to update the handset functionality, capability and protocol through reprogramming, either at a storefront or over the air. For instance, if the handset is designed with a 200 kHz RF front end, the functionality may be changed from an AMPS handset to an ANSI-136 handset, to GSM or EDGE by software change instead of purchasing and distributing new handsets. This may enable a more cost effective multimode handset with inherent flexibility and upgradeability.

- *When could software defined radios be deployed commercially, and for what services or purposes?*

It is estimated that for commercial cellular and PCS systems, base stations based on SDR technology will be available within the next 12-18 months. Availability of handsets based on this technology may be as far out as 3-5 years.

These time estimates only indicate when the first base stations or handsets based on SDR technology will be available. In order to reap the full benefits of SDR technology these new generation base stations and handsets need to have enough penetration in the network. The rate at which currently embedded infrastructures in commercial cellular and PCS networks are replaced with these new base stations depends upon business and network issues. It is estimated that it may take many years after the first availability of these products for them to reach a significant level of penetration.

- *What work is being done on software defined radios internationally, and are there any steps the Commission should take to encourage this work?*

  The ETSI ACTS program has an active software defined radio project.

B. Interoperability

- *To what extent can software defined radios improve interoperability between equipment and services using differing transmission standards?*

Software defined radios make it more cost effective and hardware efficient to implement multi-mode and multi-band base stations as well as handsets. In this sense they facilitate interoperability between equipment and services that use different transmission standards.

The cellular and PCS industry has several air interface standards such as AMPS, ANSI-136, GSM, and IS-95 that are not compatible with each other. Moreover, cellular and PCS systems operate in several different bands across the world. In order to enable roaming between networks that support different air interface standards and different bands, it is desired to have multi-mode multi-band handsets. When such handsets are built using traditional radio architectures, a lot of hardware replication is needed, which affects size, cost and power efficiency. SDR technology allows radio designers to reduce the amount of hardware.

It is very important to note here that interoperability over the air interface is just one part of the ability of a user to roam between networks that support different standards.

There are many network-related issues that have to be addressed before interoperability becomes possible. These issues range from business issues such as roaming agreements, to technical network issues such as interoperability between the signaling protocols used in the network. None of these business or network-related issues is addressed by SDR technology. Hence, it would be premature to assume that once base stations and handsets based on SDR technology are deployed everywhere, it would automatically result in all-round interoperability between networks.

- *To what extent would software defined radios move toward uniformity in standards within or across bands?*

Currently there are several different second-generation digital air interface standards for cellular and PCS systems in the United States. Operators holding cellular or PCS licenses decide which second-generation digital standard to use within their networks independent of each other. These decisions are made by each individual license holding operator based on technical and business issues. SDR technology does not address all the issues that make an operator decide which air interface standard to use. Hence, SDR may not move the cellular and PCS industry towards uniformity in standards within or across bands and SDR should not be used as an artificial means to mandate such uniformity.

- *To what extent can software defined radios be used to facilitate transitions from one technical standard to another, such as the transition mandated by the land mobile "refarming" proceeding?*

Software defined radios can be very helpful in facilitating transitions from one technical standard to another as long as the underlying hardware is able to support the computational, memory, and power requirements of the new standard. One example of such a transition in the cellular and PCS industry is the transition from second-generation digital air interface standards to third generation standards. Further upgrades and modifications can be downloaded as software updates without requiring hardware changes.

C. **Improving Spectral Efficiency and Spectral Sharing**

- *To what extent could software defined radios improve the efficiency of spectrum usage?*

In order to discuss this topic, it is important to define the appropriate terms. The term spectral efficiency is defined as the number of bits/Hz that can be transported by a wireless system. The term spectrum efficiency is defined as the ability of a wireless system to efficiently utilize a given amount of spectrum over time and geographic location.

Spectral Efficiency

Software defined radio technology is an implementation technique. It is not a spectral efficiency improvement technology. A SDR by itself cannot do much more than a traditional radio to squeeze more bits out of a given band of spectrum. The spectral efficiency of a wireless system depends upon the design of its air interface. The same air interface design can be implemented either using a traditional radio or a SDR with very comparable spectral efficiencies.

However, SDR makes it easier and more cost-effective to implement techniques that can improve the spectral efficiency of a wireless system. Examples of such techniques are smart antennas, adaptive modulation techniques, adaptive channel coding techniques, and CDMA multi-user detection algorithms. These spectral efficiency improvement techniques allow a given piece of spectrum to support a larger number of users making it easier for different users to share crowded spectrum without causing interference. Thus, SDR technology enables improvement of spectral efficiency by making it easier and more cost-effective to implement spectral efficiency techniques.

Interestingly, the techniques referred to above can be implemented using traditional radio architectures. In fact, a few of these techniques are being implemented today. However, these techniques can be implemented much more cost-effectively and in a more power-efficient manner using SDR.

Spectrum Efficiency

Spectrum efficiency quantifies the ability of a wireless system to find and utilize empty parts of a given piece of spectrum. A true SDR that can scan many frequency bands and can adapt itself to transmit/receive in those bands with the appropriate technologies can be imagined to greatly increase the ability of a wireless system to find and utilize unused spectrum. Regulatory and business issues prevent this type of operation today. Today, commercial cellular and PCS spectrum owners are restricted to operate in their own bands of spectrum with strict rules on spectrum mask and out of band emissions, and may not "sublease" spectrum. Regulatory changes allowing an operator to "lease" part of his spectrum may be made, but business, co-ordination, and control issues remain.

For operation within a given band of spectrum, spectrum efficiency can be increased with techniques such as dynamic channel allocation. Dynamic channel allocation algorithms allow cellular and PCS networks to geographically move unused frequencies from less congested cells to a congested cell to allow it to support a larger number of users. Thus dynamic channel allocation techniques effectively improve the spectrum efficiency of a given band of spectrum. Current cellular and PCS systems already support these techniques without the SDR architecture. However, a wideband software defined radio digitizes the entire band of operation such that all the channels in the system are available to the processing elements. This provides the flexibility to more easily allocate or de-allocate channels in a cell, as well as to enable more complex algorithm development and implementations.

- *What particular functions related to spectrum usage could a software defined radio perform? Could it locate free spectrum, dynamically allocate bandwidth, and enable better sharing of the spectrum?*

This is possible, as noted before, but it implies the ability to operate over larger frequency ranges, and there are many operational issues as well as regulatory issues to be overcome. This would be a long-term goal and no regulatory changes should take place at this time.

- *What changes may be appropriate for the way the Commission currently allocates spectrum?*

The FCC should take no action at this time regarding spectrum allocation. The scenarios described in the NOI are in many cases not yet technically feasible. In addition, they would not be feasible in the network until SDR radios have effectively replaced existing equipment. Even then, it is not currently clear that such scenarios would be realistic. The industry will develop and deploy SDR technology because there are a number of performance and cost issues that make it attractive to do so. Once there is a significant penetration of this technology into the market, studies may be conducted on the ability of SDR technology to enable the functionality described. At that time the FCC may wish to revisit the spectrum allocation policies to determine whether or not changes are desirable.

D. Equipment Approval Process

- *Should we approve the radio hardware, the software or the combination of them?*

In a software defined radio, the software residing in the radio has the ability to change the RF transmission characteristics of the radio. Hence, if the hardware alone is certified for operation in a certain band, a change in the software could potentially violate the spectrum mask and emission requirements for that band. Therefore, it is very important that for software defined radios, the software that controls the RF transmission characteristics of the radio should be jointly certified with the hardware that it resides upon.

It is important to distinguish between two different types of software that reside in a software defined radio. There is the type of software that can intentionally or unintentionally affect the RF transmission characteristics of a radio. For example, the software that determines the RF channel bandwidth, modulation or channel coding of the radio. Then there is the software that in no way affects the RF transmission characteristics. For example, the software that changes the look and feel of the graphical user interface on a handset, or the software for a calendar program would have no impact on the RF characteristics.

The FCC should require re-certification of a software defined radio device when there is a change in any part of the software that could potentially affect the RF transmission characteristics of that device. However, no re-certification should be required when there is a change in any part of the software that does not affect the RF transmission characteristics of the device.

- *Should we regulate who changes the software and the manner in which it is done? If so, should the Commission maintain records of such modifications?*

As noted earlier, the software resident on a software defined radio can be divided into two categories. One that affects the RF characteristics of the radio and the other that does not. As an operator of cellular and PCS networks, SBC Wireless is concerned that if anybody other than the manufacturer of the radio is allowed to change the software that affects the RF characteristics of the radio, there is the potential for this software to malfunction and cause the radio to emit RF energy in the form of interference to the system. The manufacturer of a software defined radio should not allow open access to the Application Program Interfaces (APIs) to the software modules that affect the RF characteristics of the radio.

However, the manufacturer of a software defined radio may allow third parties to access APIs to the software modules that do not affect the RF characteristics of the radio. This access should be granted after a business agreement has been made between the third party and the manufacturer to ensure that there is no malfunction of the software produced by the third party.

Conclusion

For the reasons stated herein the Commission should not consider changes to spectrum allocation approaches based on SDR. The Commission should consider requiring the certification of hardware and software in combination, if a common hardware platform is used to implement multiple standards, with any change that would have an impact on RF performance.

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